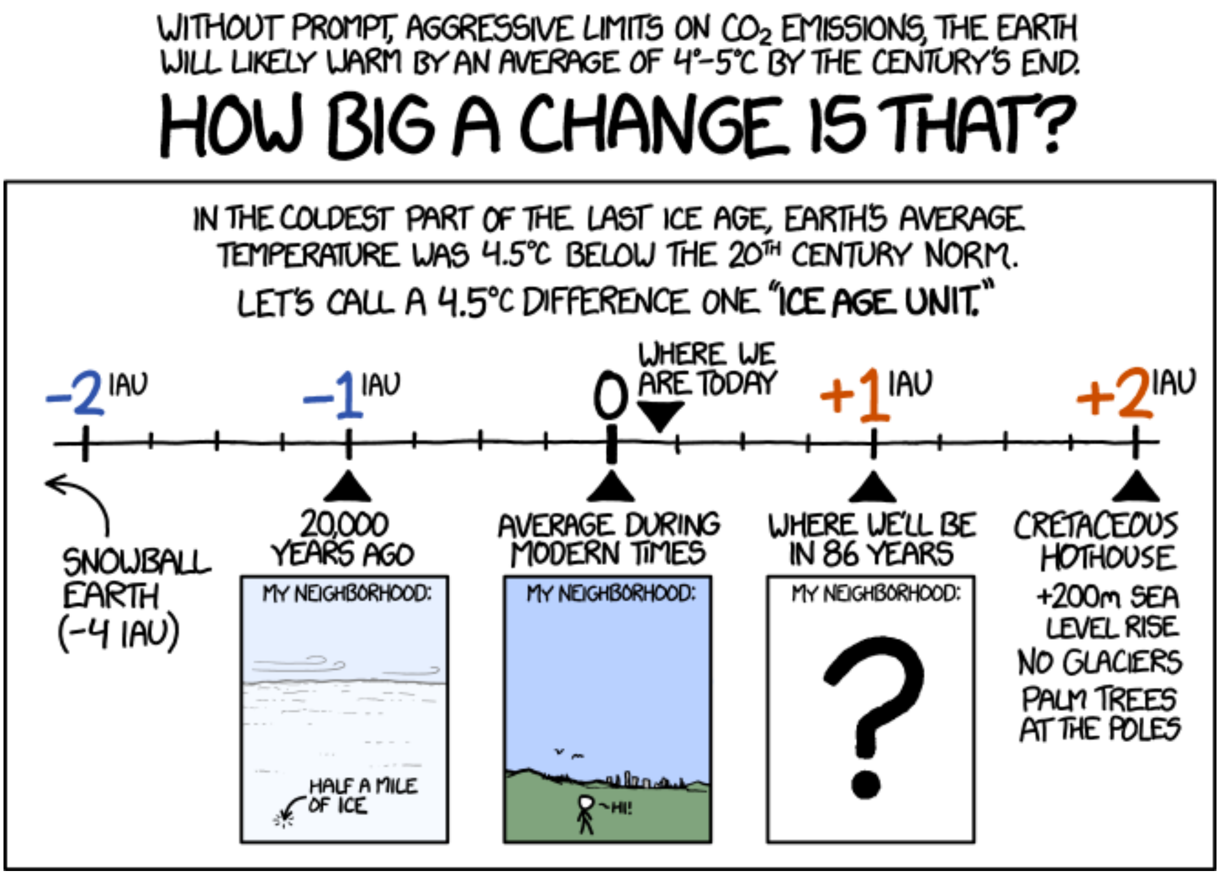
Growth Rate Required in Energy Storage

Hi Bret,

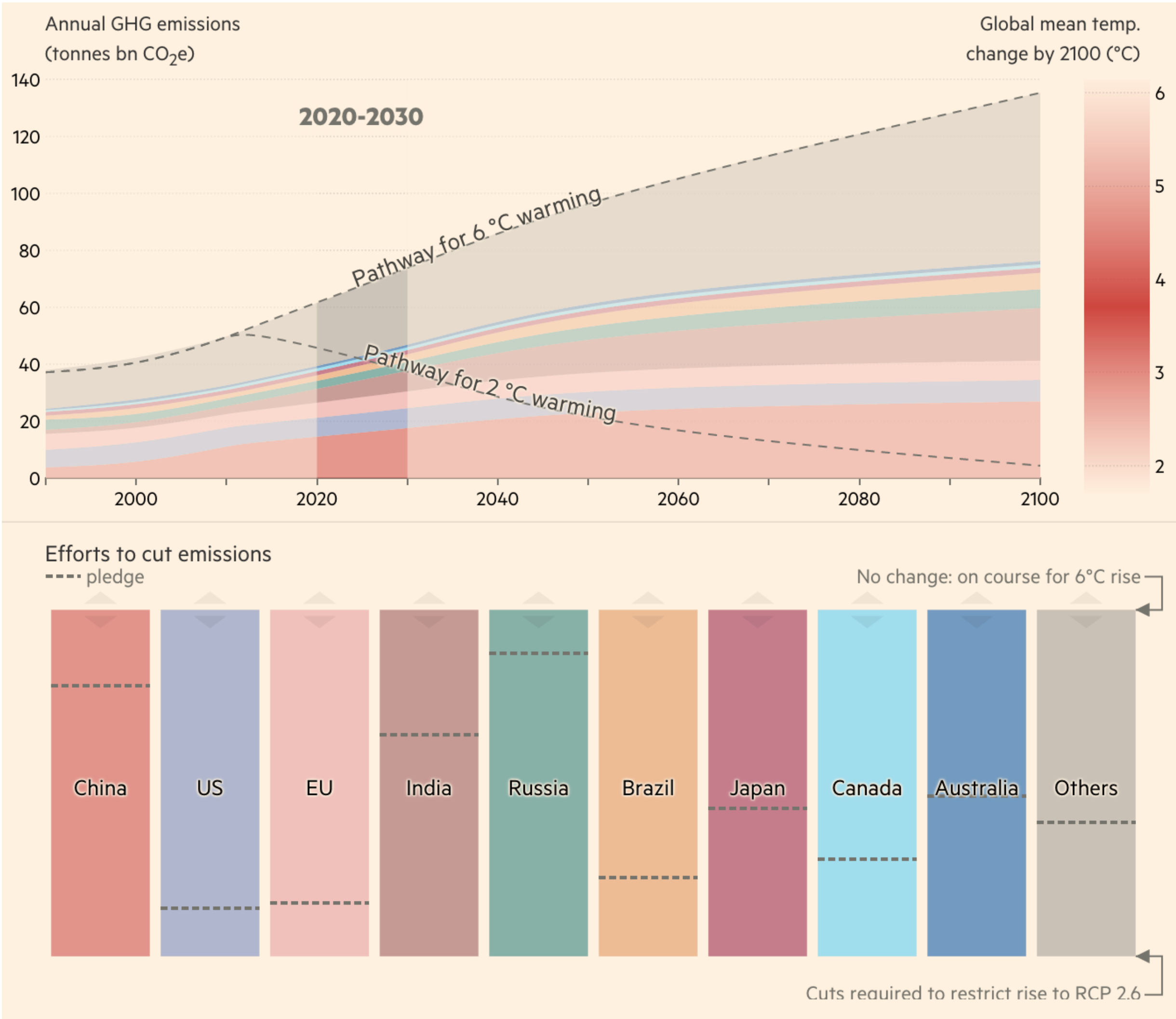
This is a simple model that allows you to get a sense for just how fast we need to grow energy storage, renewable energy (solar / wind).

First, let's calibrate around the magnitude of climate change we're talking about. Randall Munroe puts it nicely.

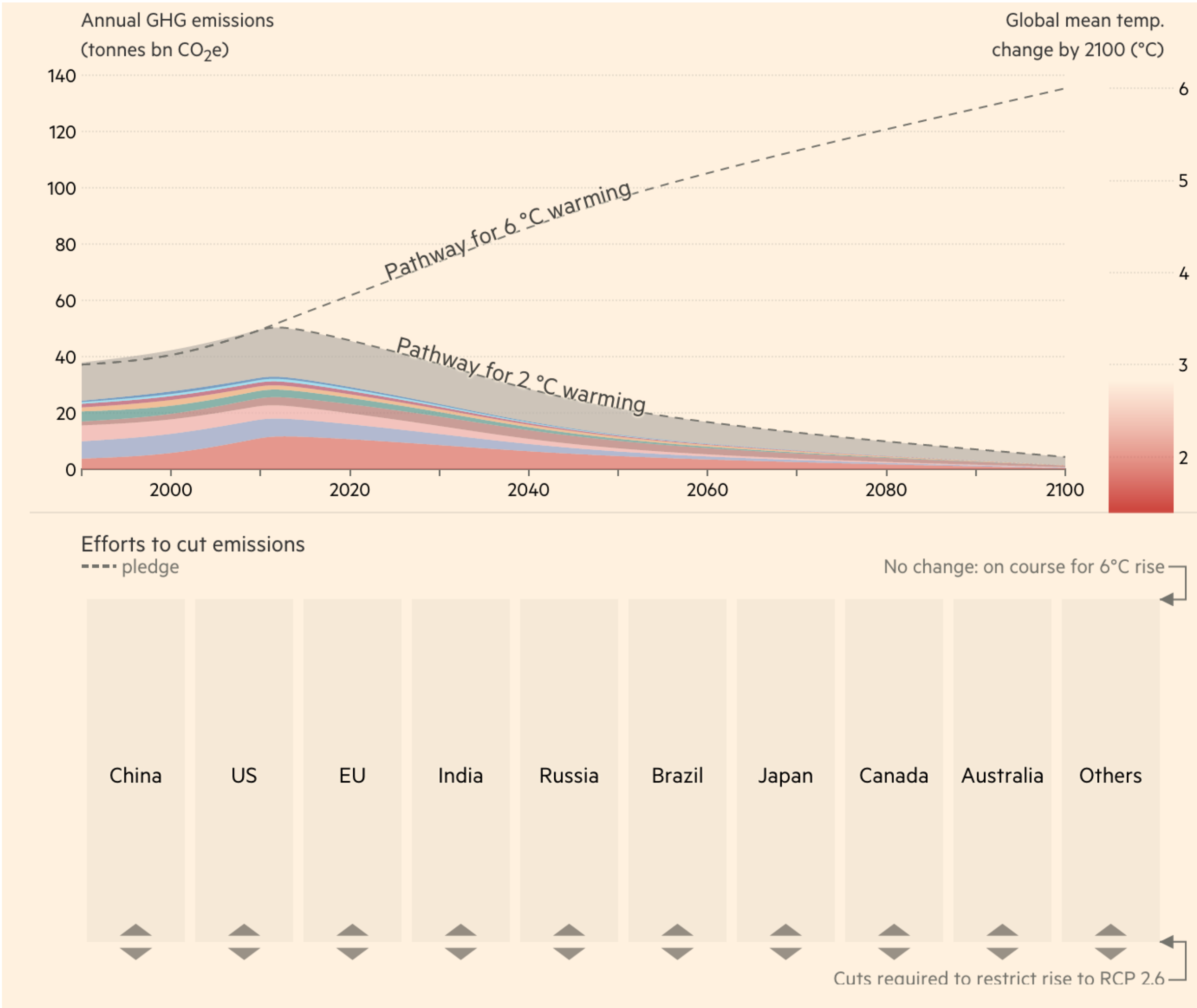


Second, let's take a look at emissions scenarios. The 'business as usual scenario' is a huge problem barring radical free market innovation or exogenous climate change.

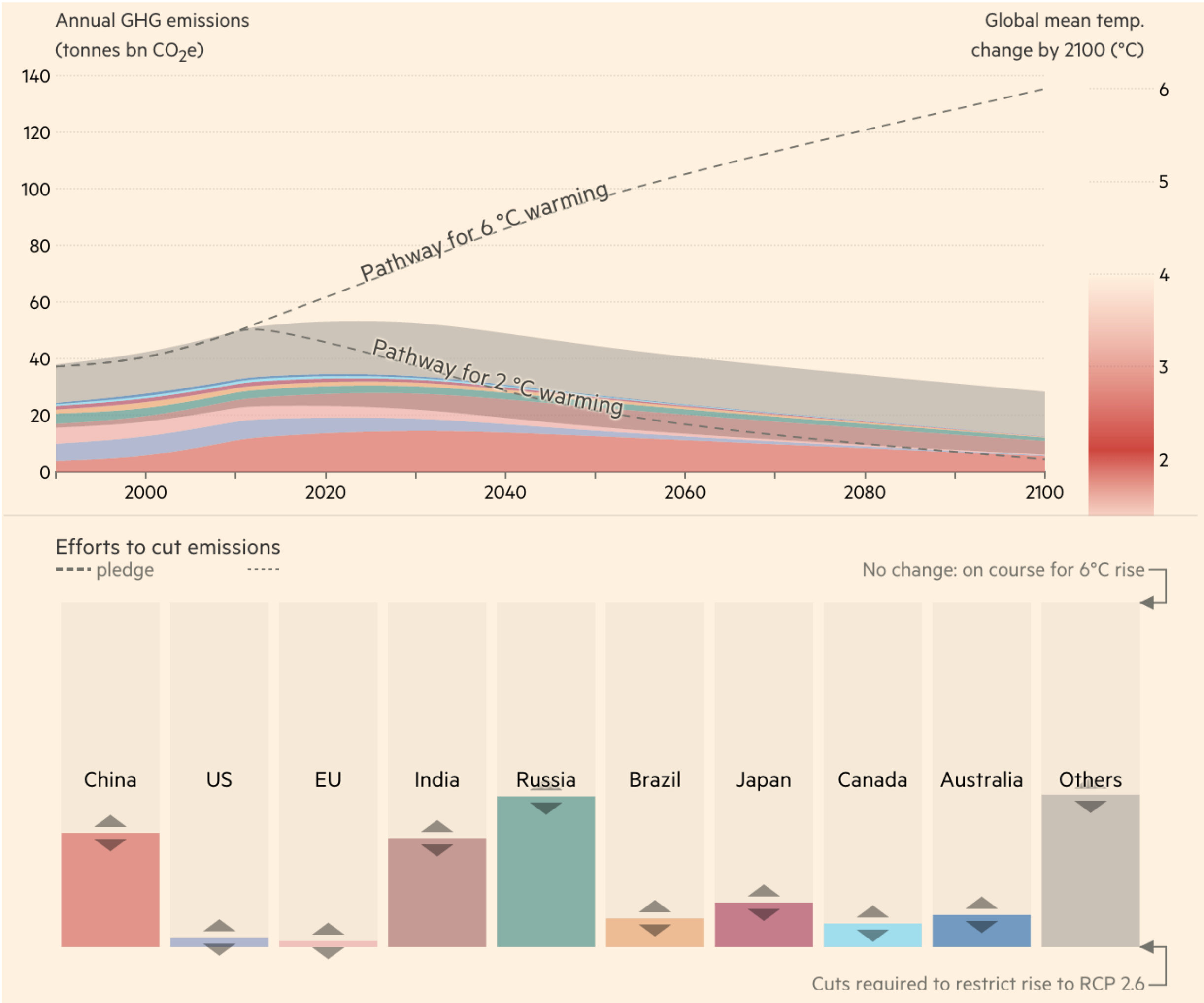
http://ig.ft.com/sites/climate-change-calculator/



The folks at FT have done us a favor by allocating the emissions reduction required for each country. You can see every country is supposed to evenly start cutting emissions, starting right away.



Personally I think it’s more challenging than that. Since there’s a lot of built infrastructure, it’s difficult to make it obsolete with either policy or new technology, since it’s still producing electricity, a valued commodity. It’s easier to limit the *increase* of emissions, which primarily effects developing economies. Also, automobiles and lighting and computers keep improving in efficiency, and possibly electrify. So my own guesses as to the emissions reduction possible with technical improvements and free market improvements, but only limited government intervention and policy support, are below.



You'll note in my scenario above, the delta between the 6° C pathway and my pathway is about 50 - 60 giga-tonnes of CO2 per year in 2050. That's approximately 125% - 150% of today's emissions, representing about as much energy displacement.

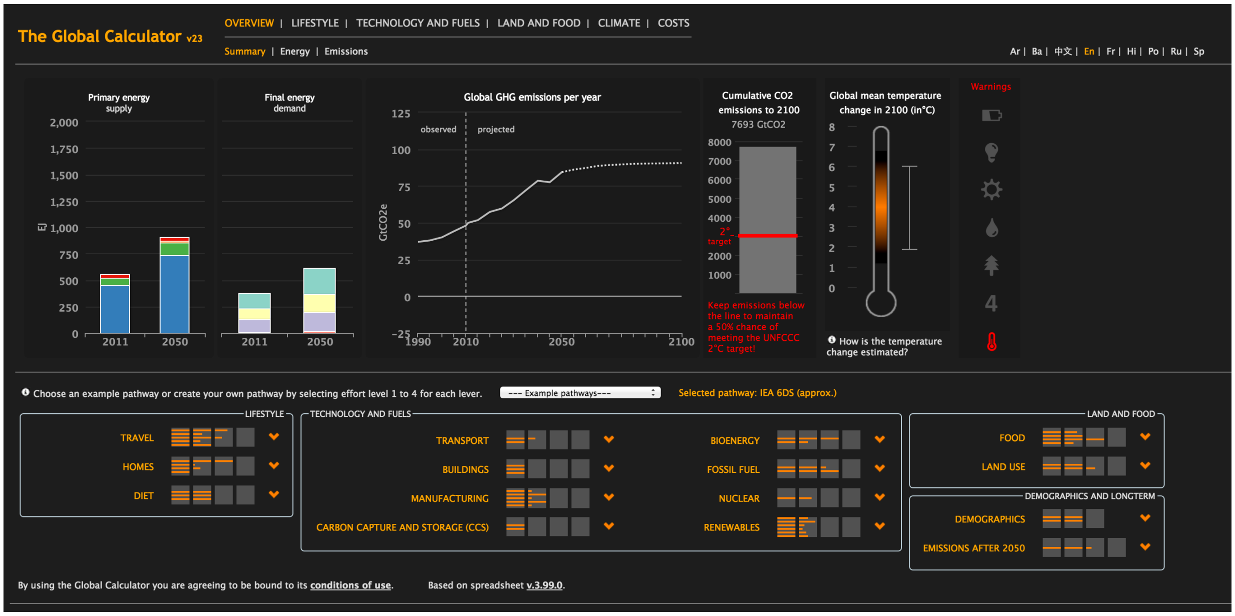
Let's take 2050 as a make it or break it date, and investigate a little further just how much storage we need if we want to simply avoid an increase in emissions from the increase in our primary energy needs.

Let's figure out how much solar / wind we need.

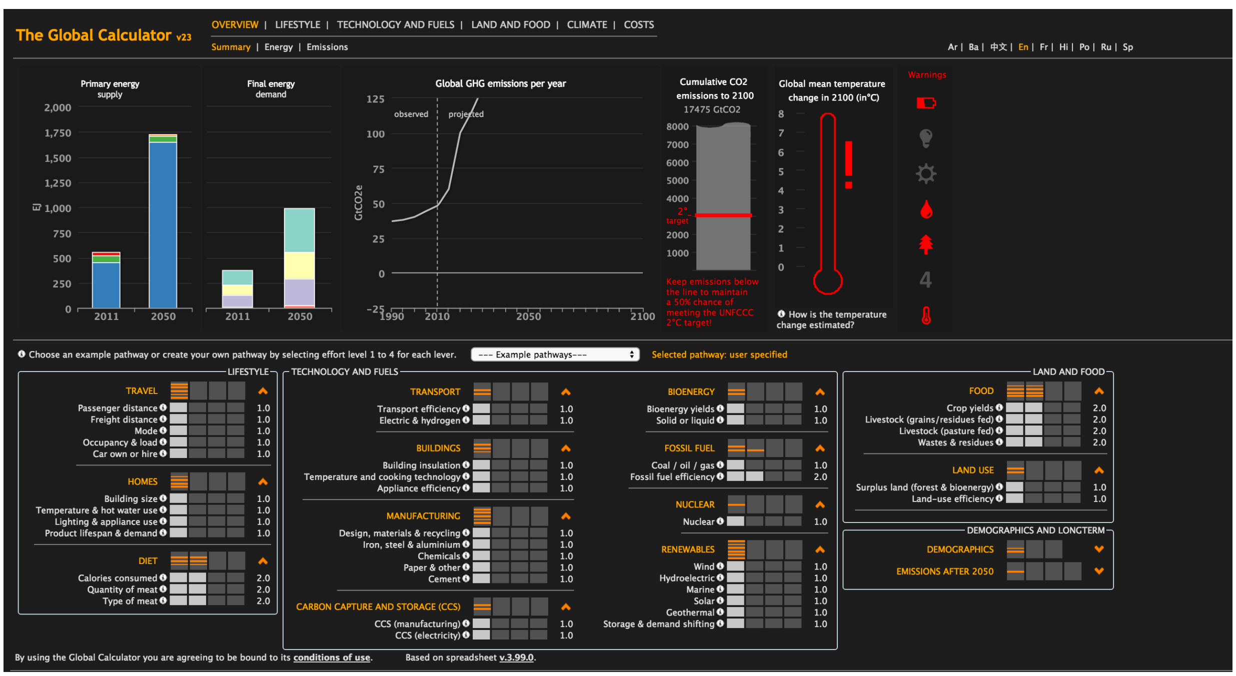
There's a more detailed 'global calculator' that allows you to assign ambitious or extremely ambitious projects to various areas -- renewables, efficiency, diet, and so on.

Their baseline scenario is here:

http://tool.globalcalculator.org/globcalc.html?levers=22rfoe2e13be1111c2c2c1n31hfjdcef222hp233f211111fn2211111111/dashboard/en



A scenario I created with fairly minimal abatement is here:
http://tool.globalcalculator.org/globcalc.html?levers=1111111111111111111111121111111122221221111111121 2211111111/dashboard/en



The purpose of this is to figure out just how much primary energy we need. The delta between 2011 and 2050 is between 500 and ~ 1000 exajoules, in these two cases.

In[27]:= **Convert 1000 * 10^18 Joule / (1 Year) to Watt**

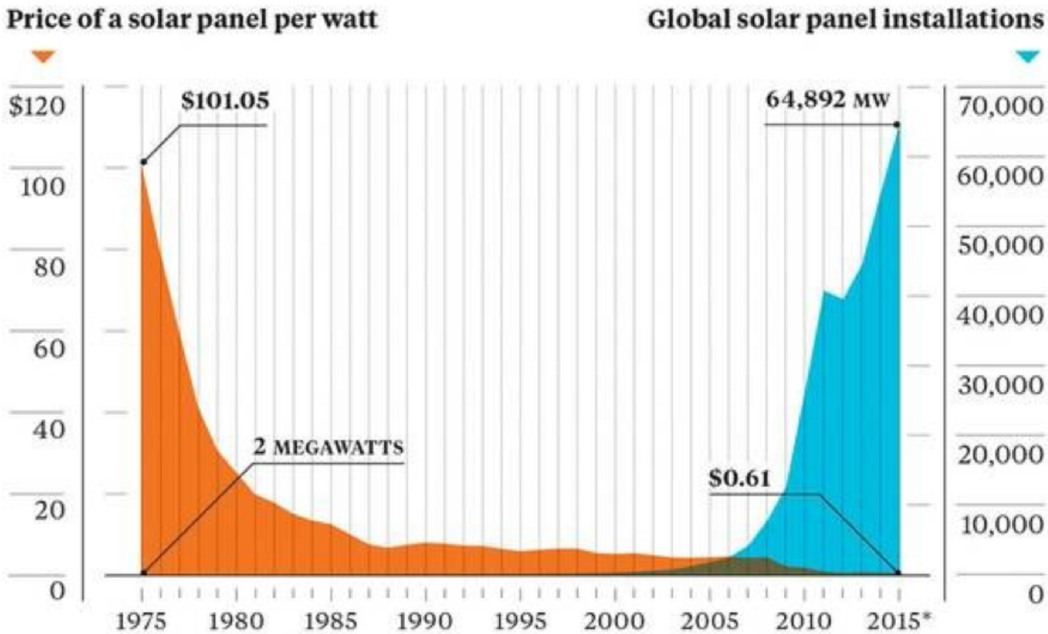
WolframAlphaClient`Private`podTitle [{title → Result}, {1, 1, Output }]

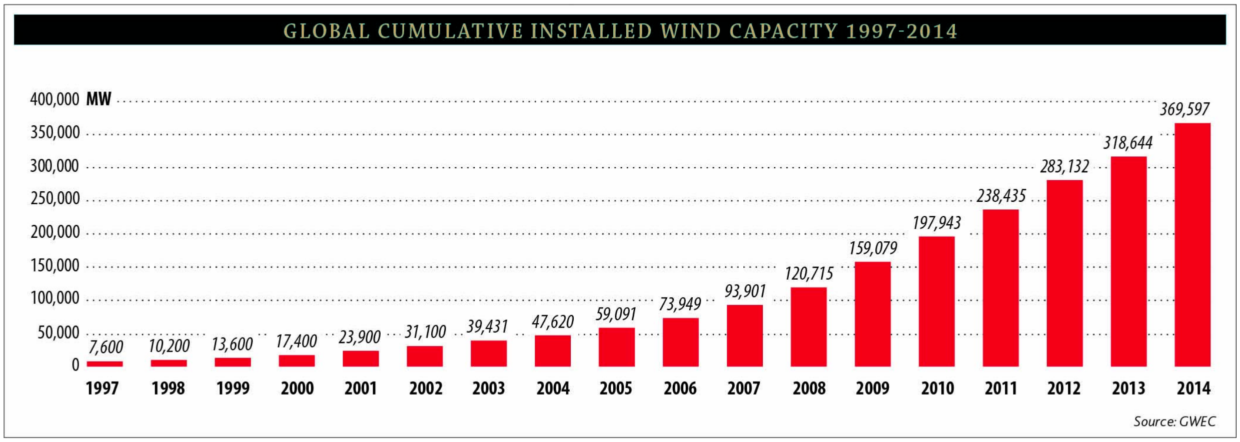
WolframAlphaClient`Private`queryBlobMathematicaForm[3.171` × 10^{13} W]

Out[27]= 3.171×10^{13} W

So that's between 32 TW and 15 TW averaged. The trouble is that solar projects and wind projects typically generate only 20% of their peak power averaged throughout the year, because the sun is not always at its strongest. Hence, we need around 5x this as peak power -- between 160 TW and 75 TW of added solar or wind.

The current historical installation of solar is 65 GW. There was a huge breakthrough in the 2005 - 2009 period, when true cost competitiveness in many markets came into being.



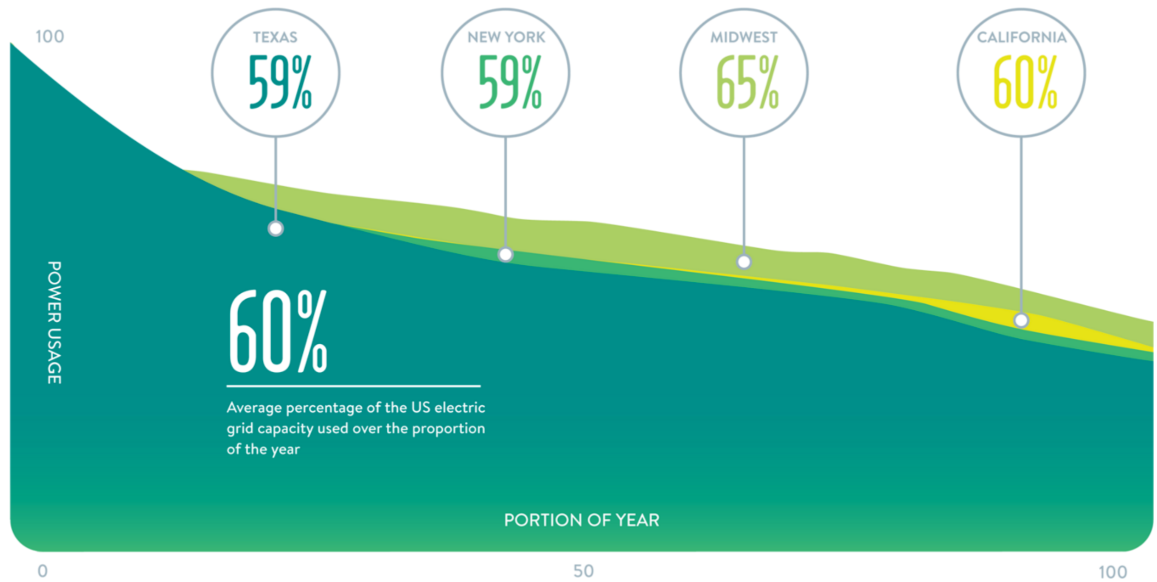


The current installed wind capacity is about 370 GW. So, wind power is currently in the lead. However, both need to grow exponentially. And the solar growth rate is higher, at about 30% annually, with wind at only about 15% annually. The biggest reason for this is that wind is much less geographically well distributed. It is the most economic form of power in places with lots of wind -- costal regions, flat regions near lakes, mountain passes, and at high altitudes. But these places are increasingly taken up. It is possible to repurpose land at wind farms with newer and taller towers and turbines but this is a slower route. Conversely, solar is easier to deploy -- it is a much more disruptive innovation at the distributed scale. In this analysis, then, it is probably best and simplest to bet on the fastest growing exponential -- solar -- unless wind can catch up with a similar growth rate. Makani Power or deployment optimization might help.

Now, how much storage do you need? Typically, the capacity factor of the electrical grid is about 60%. This means that you need dispatchable power (or demand you can easily shed or relocate) equal to about 1/0.6 = 167% of the average power usage.

Nearly Half of the Electric Grid Capacity is Underused

Inefficient diesel and gas peaker plants supply electricity during the times of greatest demand. The grid resources (wires, transformers, etc.) required to transport this peak power are left underutilized during non-peak times. Low-cost storage can increase grid utilization without adding more wires.



Now, we're adding 15 - 32 TW of new average demand. This implies that to meet that, you need 25 - 53.3 TW of peak energy storage power dispatchability to provide the power. Additionally, you need have enough hours of duration to store it. The excess supply of solar and wind: {75 TW of supply} - {15 - 25 TW of demand} or {160 TW of supply} - {32 - 53.3 TW of demand} is your fuel. If you're lucky, the wind and solar and baseload generation and demand peaks match up so that you don't need much more than the 25 - 53.3 TW of storage / (or demand shifting), but on the upper end of possibility we may need to have storing rates of nearly 100 TW to supply the ~50 TW of demand. Luckily, LightSail's tech does have this capability.

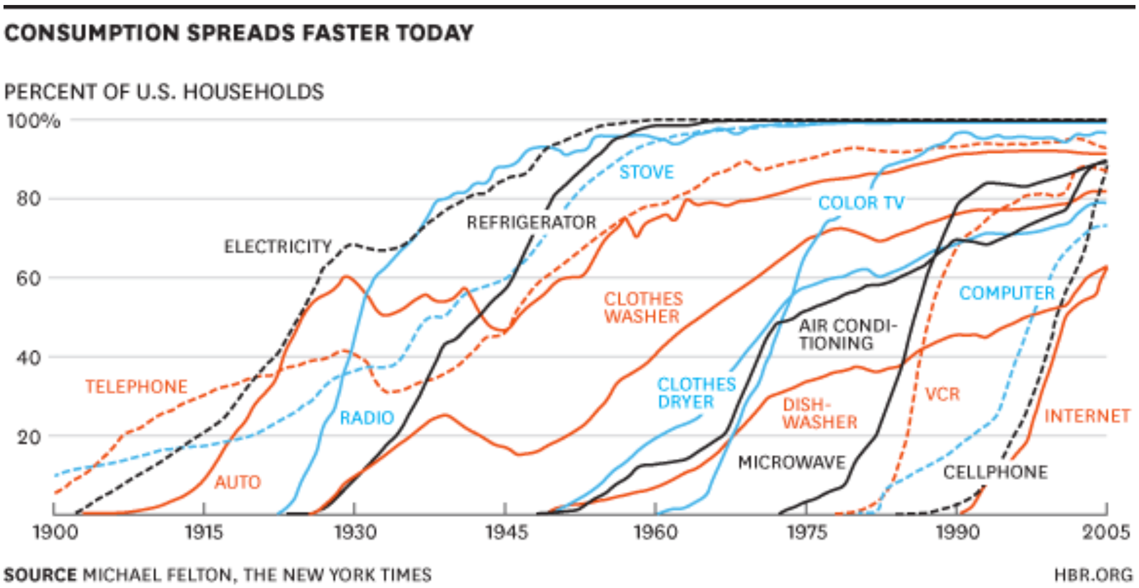
Now, Amory believes we'll be able to find this much demand shifting. Personally, I think it will be difficult to find, for example, 16 TW, which is equal to the entire current peak electricity demand on the planet! But let's assume on the ambitious side that Amory can find it.

We thus have our range. It's pretty big: we need between 10 TW and 100 TW of energy storage capability by 2050, just to *avoid* emissions increases from the energy sector.

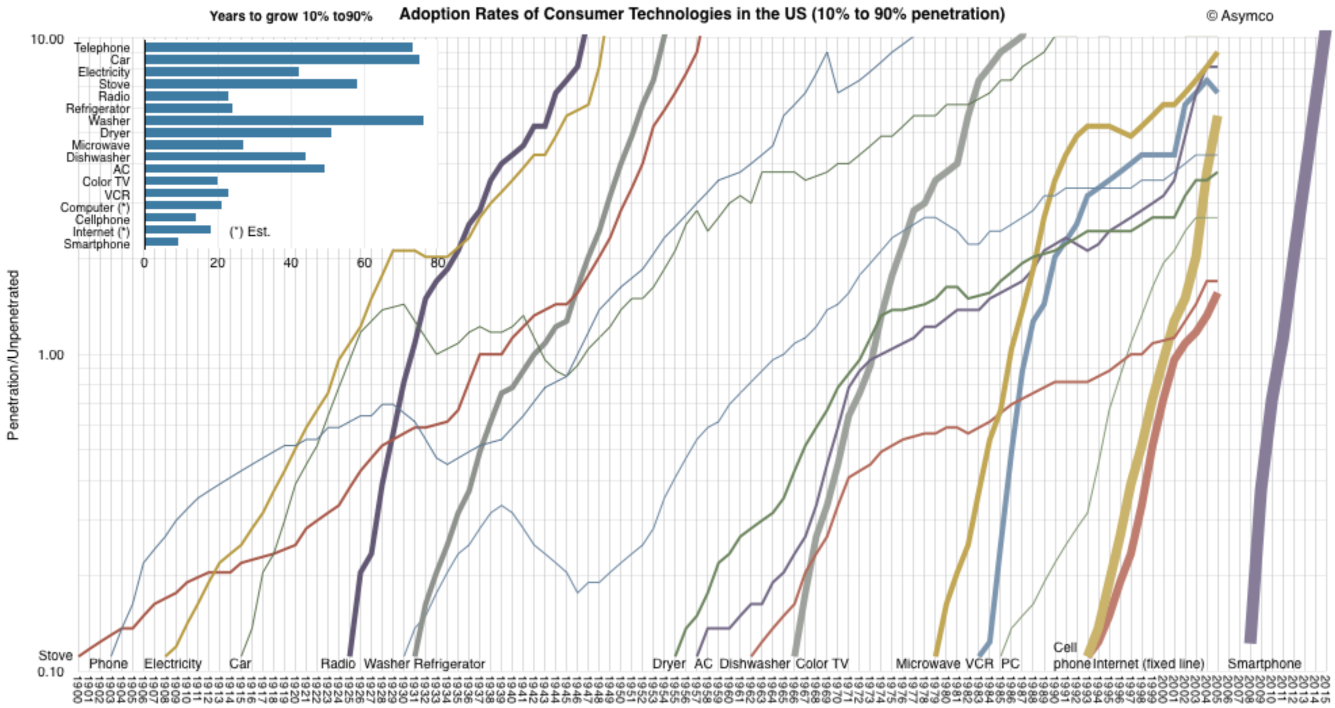
If we want to follow the 2° C curve, the supposed international target, instead, we instead need this range of energy storage by *2030 - 2035*

How fast is that scale up, in historical terms? Here are a bunch of views into technology adoption data.

The technology adoption curves are S-curves -- the annual growth rate usually starts modestly at product introduction, and as it makes breakthroughs in attractiveness accelerates. Finally, once it reaches mainstream adoption, the growth rate slows, as there simply aren't as many new customers.

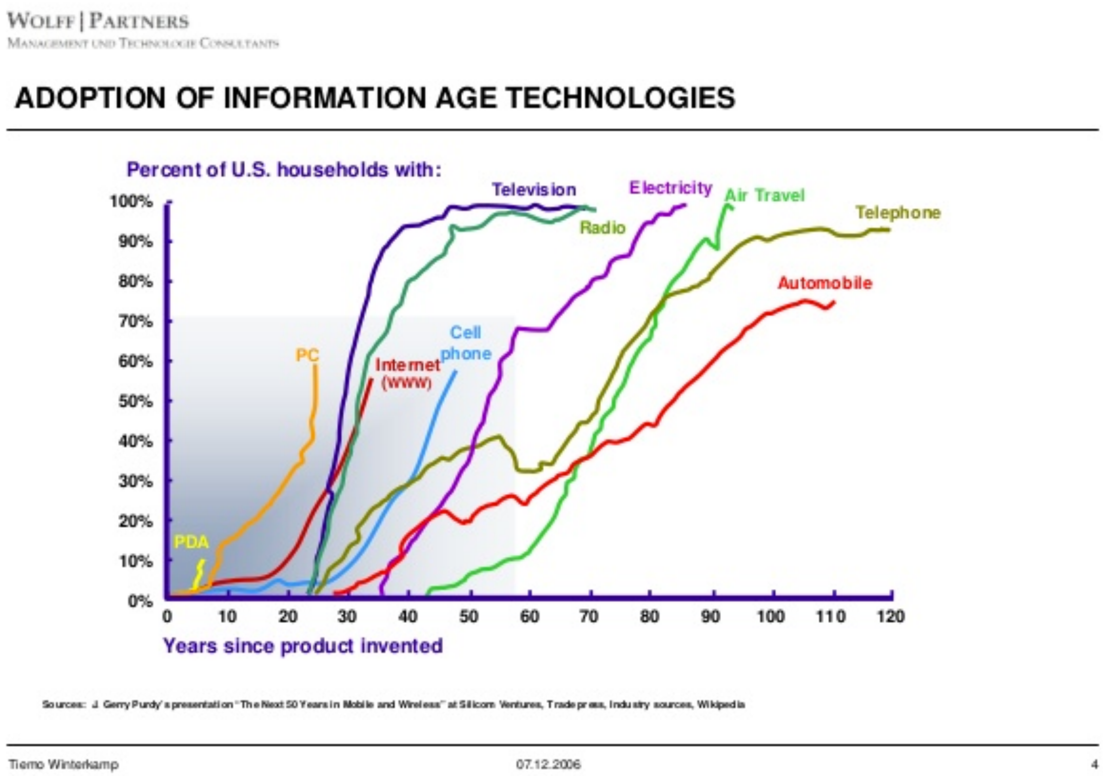


This one has a bit more data and views on how long it took to get from 10% to 90%.

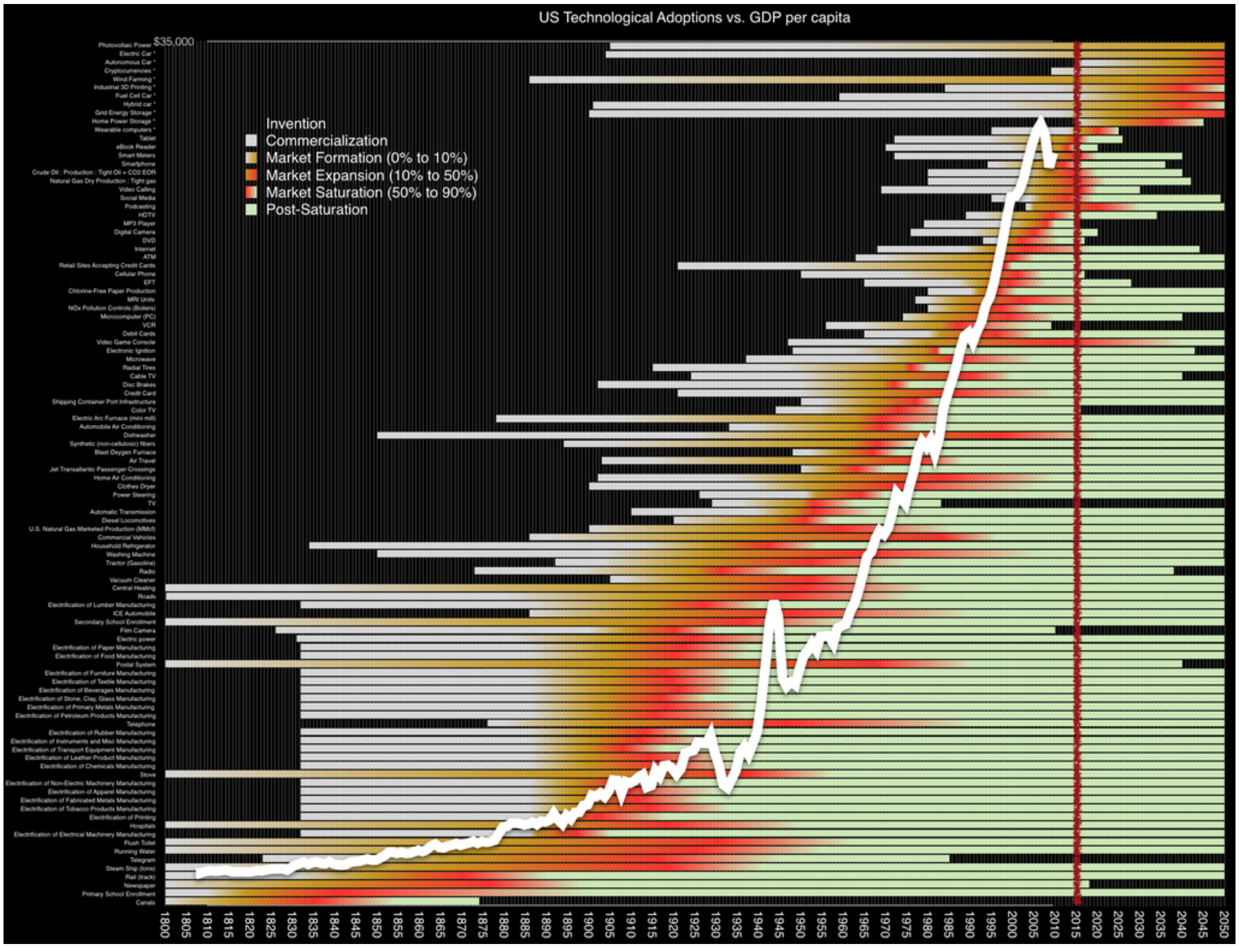


http://image.slidesharecdn.com/061121twilc-140805103706-phpapp01/95/innovation-life-cycle-4-638.jpg?cb=1407235176

This is perhaps a better representation of the same data, showing household usage vs introduction rates.

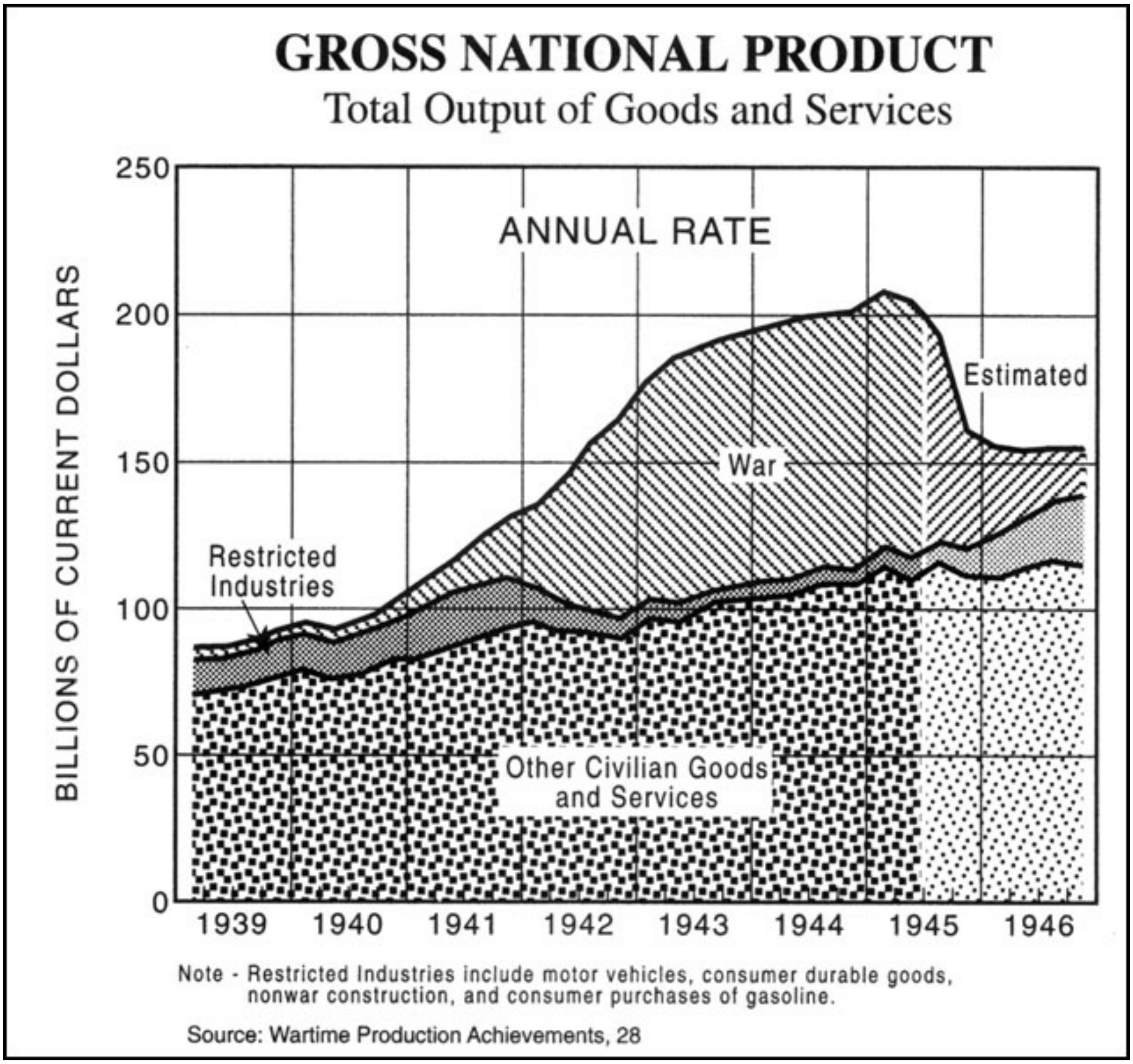


This one has a lot more data than the others, but is barely readable (maybe you can find the original).



Mobilization in World War II (from https://www.ibiblio.org/hyperwar/USA/BigL/BigL-1.html)

In the years 1940 - 1942, war production represented a tripling each year. In 1943 and 1944 the growth rate slowed to approximately 30% and about 0%, hitting obvious limits as half of all production was now geared to wartime usage.



Let's compare energy storage and solar for the 4 ° C and 2 ° C cases, and to these wartime mobilization rates. Note, we start at a mere 10 MW -- this is the expected LightSail internal production in our first commercial year, 2017. There's more energy storage out there of course, but in our estimation it has less scaling potential.

In[52]:=
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   {
    LogPlot[
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      StorageNeeded,
      SolarStartingPoint * (SolarAGR + 1.0)^(t - SolarStartDate),
```

```
       SolarNeeded
      },
      {t, 2015, 2100} ,
      AxesLabel → {"Year", "Power (W)"},
      PlotRange → {{2015, 2050}, {10^6, 10^15}},
      PlotLabel → LogPlotLabel,
      ImageSize → {640, 400},
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     ]
    },
    {
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Storage Annual Growth Rate: ``%
Storage Doubling Time: `` Years (`` Months)
Solar Annual Growth Rate: ``%
Solar Doubling Time: `` Years (`` Months) ",
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       NumberForm[Log[2] / Log[StorageAGR + 1.0], 3],
       NumberForm[12 * Log[2] / Log[StorageAGR + 1.0], 3],
       NumberForm[(100 * SolarAGR ), 3],
       NumberForm[Log[2] / Log[SolarAGR + 1.0], 3],
       NumberForm[12 * Log[2] / Log[SolarAGR + 1.0], 3]
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   }
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      Control[{{StorageStartDate, 2017}, 2015, 2050}],
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      Control[{{StorageAGR, 2.00}, 0, 5.0}]
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    Column[{
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      Control[{{SolarStartDate, 2015}, 2015, 2050}],
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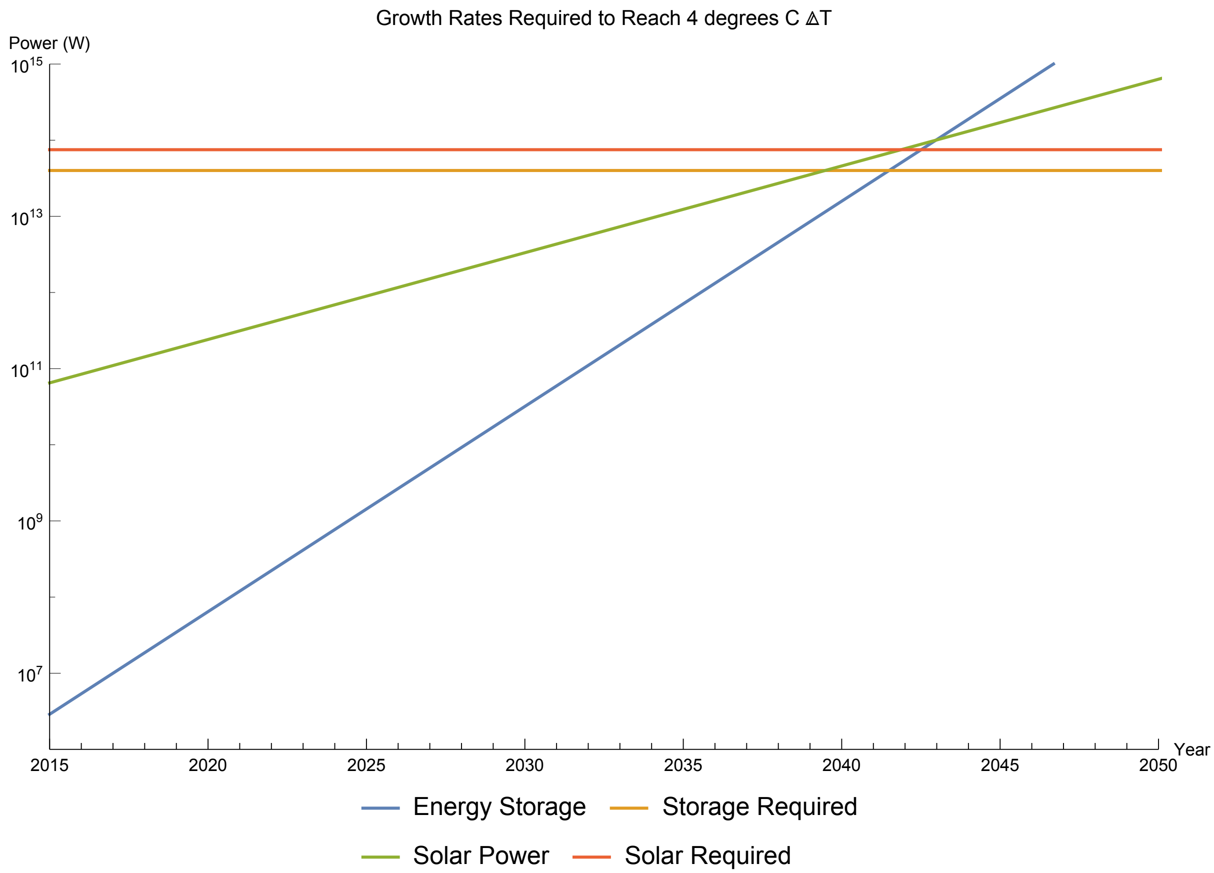
      Control[{{SolarAGR, 0.30}, 0, 5.0}]
     }]
   }],
  ControlPlacement → Bottom]
```

First, below, the 4 ° C ∆T case (about 1 ice age unit!). This doesn't have complete electricification of vehicles, but at least the electricity sector doesn't have a dramatic increase in emissions. Storage needs to double in capacity in 13 months, faster than Moore's law.

Out[52]=



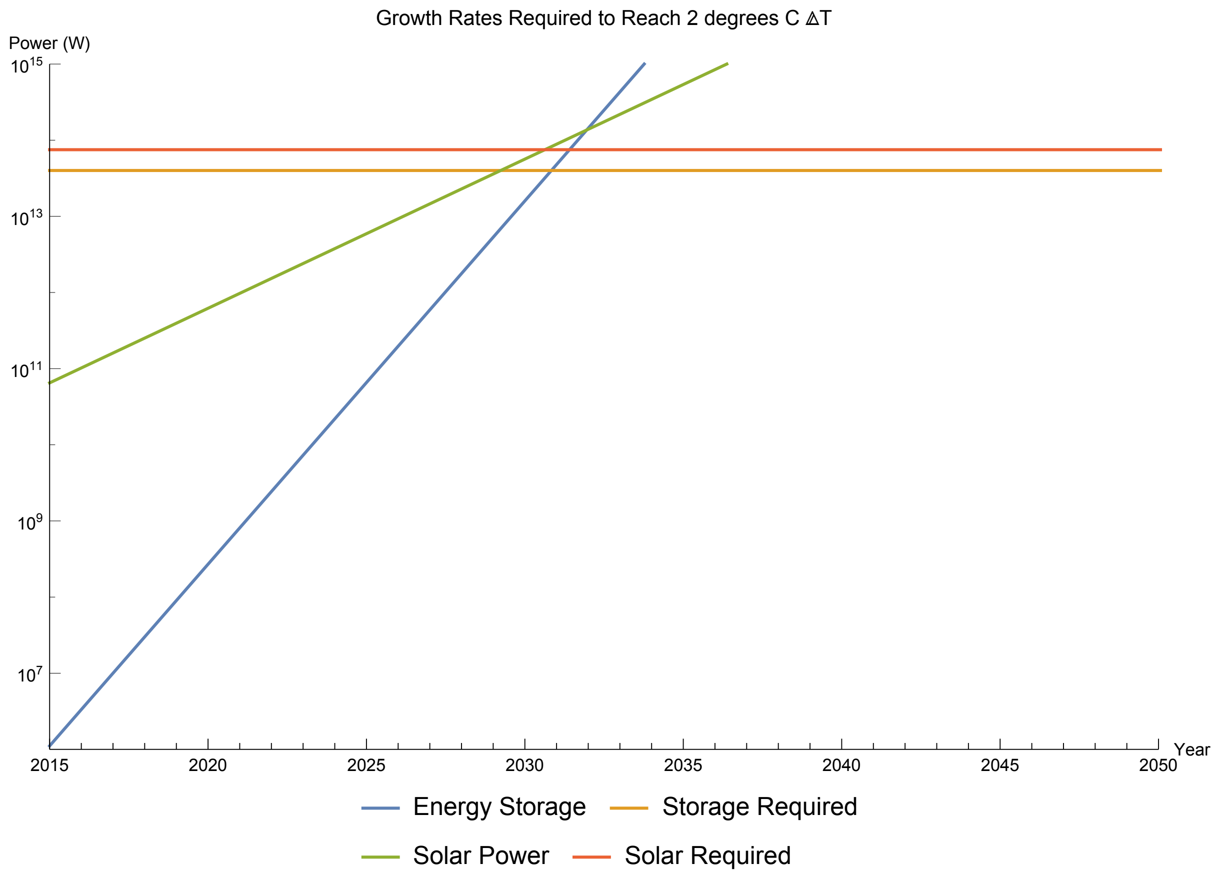
Storage Annual Growth Rate: 86.%
Storage Doubling Time: 1.12 Years (13.4 Months)
Solar Annual Growth Rate: 30.%
Solar Doubling Time: 2.64 Years (31.7 Months)

LogPlotLabel "Growth Rates Required to Reach 4 degrees C ∆T"

Storage Inputs	Solar Inputs
StorageStartingPoint	SolarStartingPoint
StorageStartDate	SolarStartDate
StorageNeeded	SolarNeeded
StorageAGR	SolarAGR

Second, below, the 2 ° C ΔT case. You really need to scale to 10 - 50 TW of storage and solar around 2030-2035 barring revolutions in energy efficiency elsewhere. It’s tricky. You have to scale solar and storage much faster

Out[52]=



Storage Annual Growth Rate: 200.%
Storage Doubling Time: 0.631 Years (7.57 Months)
Solar Annual Growth Rate: 57.%
Solar Doubling Time: 1.54 Years (18.4 Months)

LogPlotLabel "Growth Rates Required to Reach 2 degrees C ΔT"

Storage Inputs

StorageStartingPoint

StorageStartDate

StorageNeeded

StorageAGR

Solar Inputs

SolarStartingPoint

SolarStartDate

SolarNeeded

SolarAGR

The rates required roughly match, for storage, the wartime mobilization rates (tripling every year) for the years 1940 - 1942, but instead of doing it for three years, you need to do it for 15. You also need to nearly double the solar growth rate from 30% to 60%. Although this may be doable, it is certainly still a tall order.

Finally, let’s compare to *batteries* and current / projected growth rates, and solar and current growth rates. You could use two baselines: the global power storage market using battery storage and their anticipated growth rates, or the general batter manufacturing market and their actual growth rates.

First the power storage market and the projected growth rates.

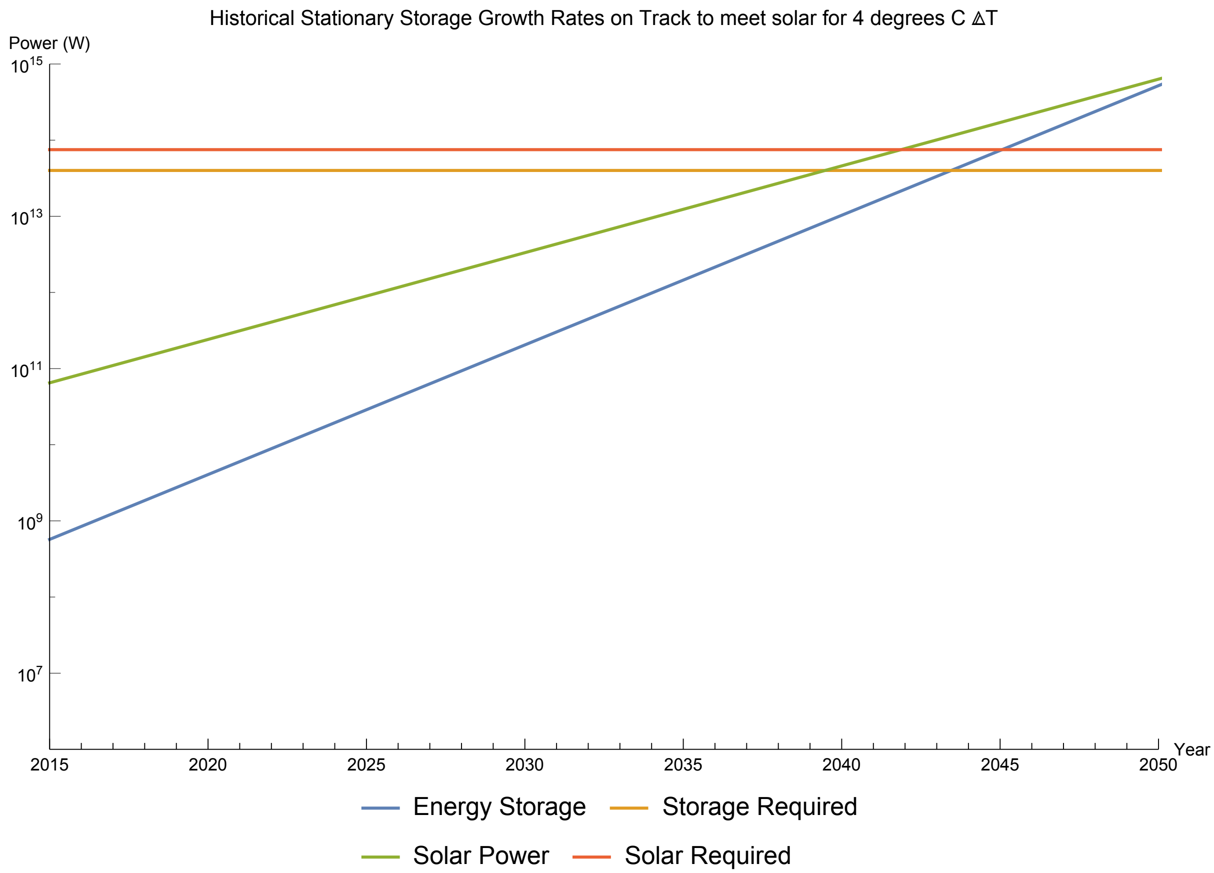
(From http://storage.pv-tech.org/guest-blog/global-market-surpasses-1gwh-milestone-in-a-landmark-year-for-grid-storage)

We'll kick off this blog with some headline findings

- As of October 2015, 1,788MW and 3,460MWh of grid storage has been deployed globally on a cumulative basis, representing more than 841 installing and operating projects
- Since 2011, the global market for grid storage has shown a combined annual growth rate (CAGR) of 33% when rated by power capacity and 20% when rated by energy capacity, while Li-ion has grown much faster than the global market with CAGRs of 48% and 62% by power and energy, respectively
- Lithium ion (Li-ion) batteries have captured the majority of the annual market on an energy basis since 2011, and cumulatively account for 70% of the market by power and 39% by energy

We have about 1788 MW of battery storage existing in stationary grid storage today. Historical trends show a annual growth rate of about 33% by power, although for lithium ion, a lead contender, the growth rate is faster, 48% by power. Let’s use this number and just use 1788 MW * 70% = 1251 MW as a base, and let’s use the lithium ion growth rate.

Out[52]=



Storage Annual Growth Rate: 48.%
Storage Doubling Time: 1.77 Years (21.2 Months)
Solar Annual Growth Rate: 30.%
Solar Doubling Time: 2.64 Years (31.7 Months)

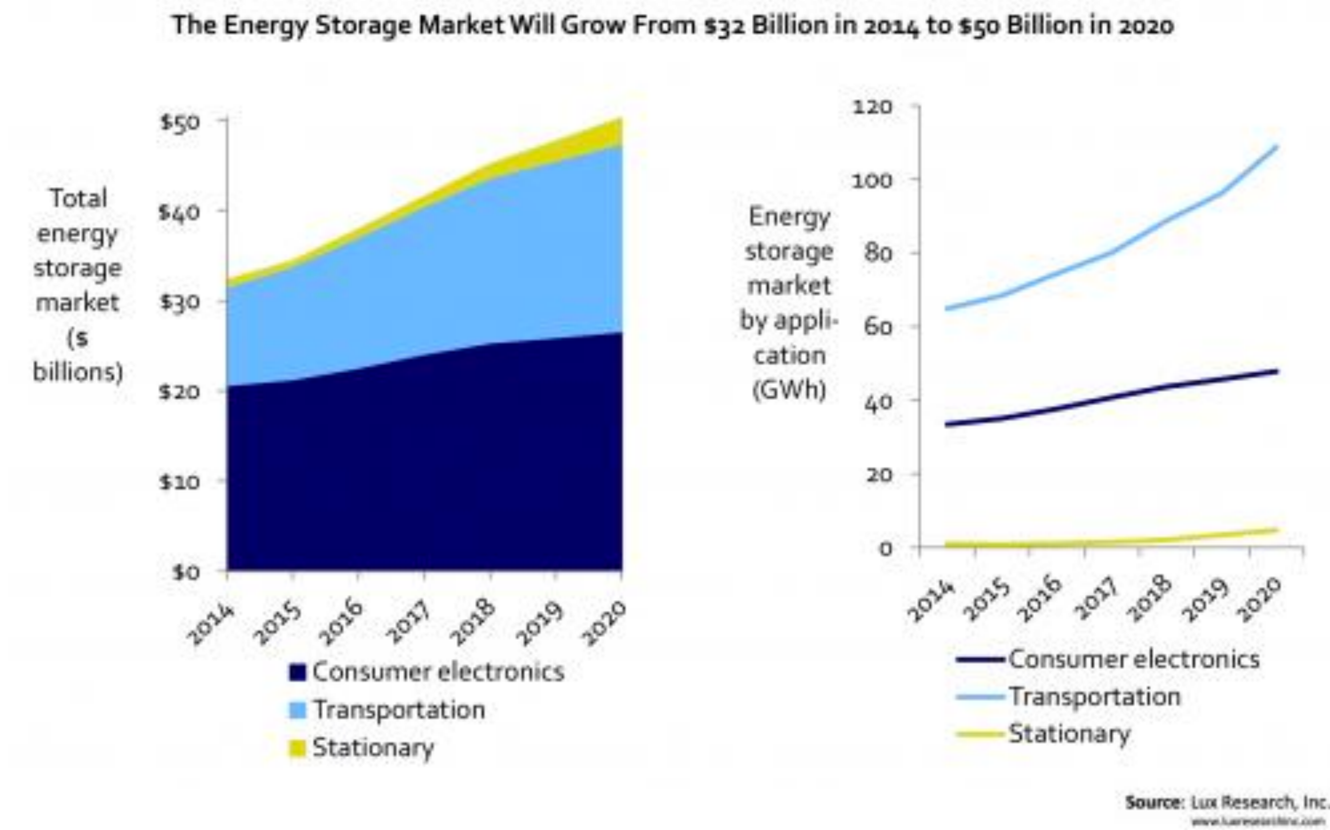
LogPlotLabel "Historical Stationary Storage Growth Rates on Track to meet solar for 4 degrees C ∆T"

Storage Inputs	Solar Inputs
StorageStartingPoint	SolarStartingPoint
StorageStartDate	SolarStartDate
StorageNeeded	SolarNeeded
StorageAGR	SolarAGR

The above scenario does balance out and provides the storage necessary for solar to support a roughly 4 ° C scenario -- one ice age unit. It’s still a huge growth rate -- nearly the rate of Moore’s law, and faster than almost all of the previously shown adoption curves.

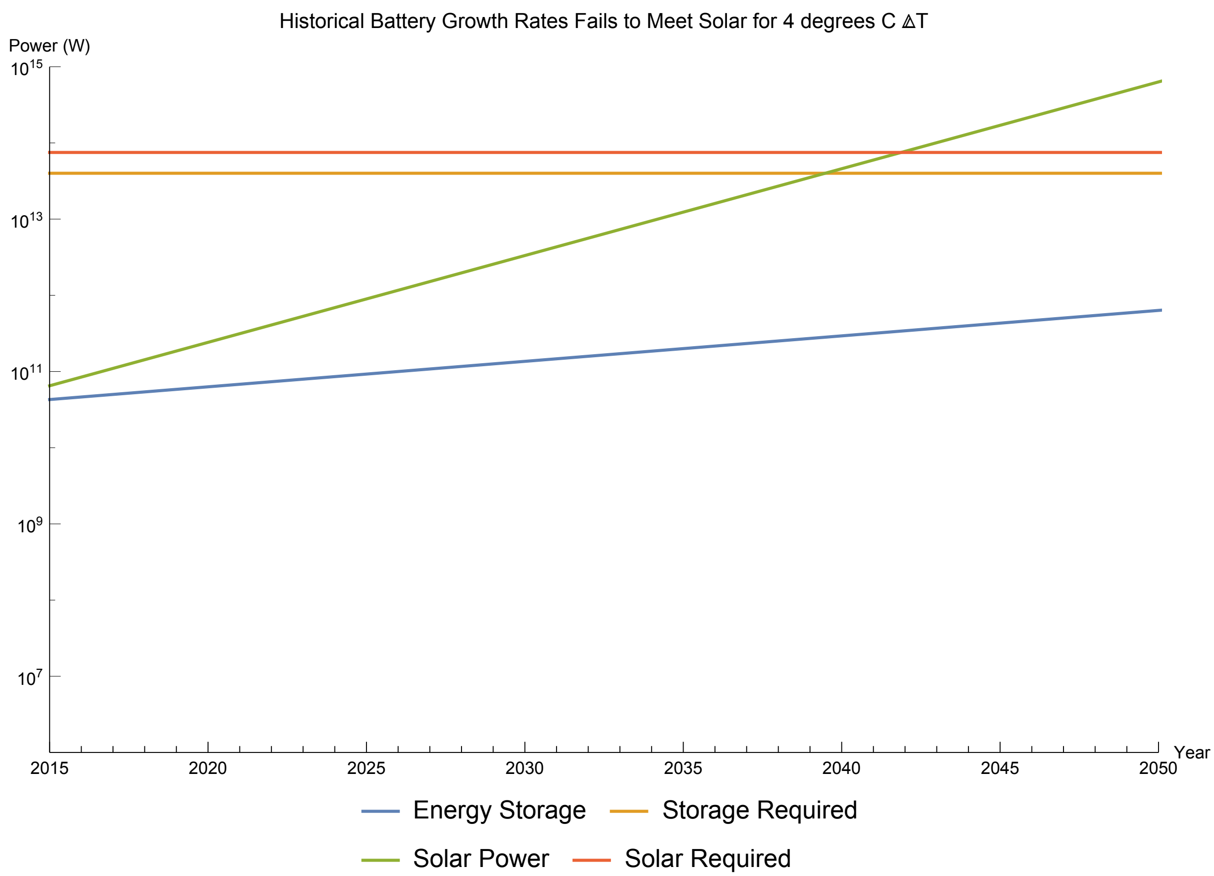
But now let’s take a look at the actual current and anticipated battery supply.

Lux anticipates given the overall battery supply a annual growth rate of 8%, and a roughly 100 GWh (perhaps 50 GW) existing supply.   (source: http://www.luxresearchinc.com/news-and-events/press-releases/read/energy-storage-market-rises-50-billion-2020-amid-dra-
matic)-



The below scenario shows that it's not even close. What this says is that when the grid energy storage supply using batteries is low, you can make use of the existing supply base -- for a while. But by about 2025 you're using up almost all existing supply -- necessitating a huge manufacturing scale up effort.

Out[52]=



Storage Annual Growth Rate: 8.%
Storage Doubling Time: 9.01 Years (108. Months)
Solar Annual Growth Rate: 30.%
Solar Doubling Time: 2.64 Years (31.7 Months)

LogPlotLabel "Historical Battery Growth Rates Fails to Meet Solar for 4 degrees C ΔT"

Storage Inputs	Solar Inputs
StorageStartingPoint	SolarStartingPoint
StorageStartDate	SolarStartDate
StorageNeeded	SolarNeeded
StorageAGR	SolarAGR

And keep in mind, this still isn't the scenario we're aiming for. We want 1/2 an ice age unit of change.

At least with LightSail, we can, mostly, use existing manufacturing capacity. Even then we're likely to run into limiting factors -- especially on the 2 ° C scenario. And to reach that we at least need to be aware of how tall an order it is!

Cloud Deployment Beta

In[54]:=
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      },
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Storage Annual Growth Rate: ``%
Storage Doubling Time: `` Years (`` Months)
Solar Annual Growth Rate: ``%
Solar Doubling Time: `` Years (`` Months) ",
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       NumberForm[(100 * SolarAGR ), 3],
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      Control[{{StorageAGR, 2.00}, 0, 5.0}]
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    Column[{
      Item["Solar Inputs", Alignment → Center],
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        Control[{{SolarStartDate, 2015}, 2015, 2050}],
        Control[{{SolarNeeded, 75 * 10^12}, 1 * 10^12, 200 * 10^12}],
        Control[{{SolarAGR, 0.30}, 0, 5.0}]
       }]
     }],
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